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Thermoelastic Effects in Sliding Systems

Final Report

Northwestern University
Technological Institute
Evanston, Ill. 60201

by

A. L. Kistler

20 April 1981

ABSTRACT

The Northwestern high speed rubbing apparatus has been modified to remove certain ambiguities in output data interpretation. Some experiments have been carried out with the modified apparatus, and data on friction, temperature, and contact resistance have been obtained for a graphite-steel contact region. No thermoelastic instability effects were observed over a speed range of 70 M/sec.

INTRODUCTION

The purpose of the work reported here is to understand the processes occurring at the contact region between two surfaces moving at large relative velocities. This work continues the overall effort reported in references 1, 2, and 3, and is detailed in reference 4.

The previously reported work describes the design and construction of the test equipment, and presents some experimental results. These results suggest the occurrence of thermoelastic instability in the contact region, but the evidence is indirect and inconclusive. The main conclusions reached were:

1. Heat generated in the graphite-steel contact was primarily conducted into the steel. Very little is carried off by wear particles.

2. The friction coefficient is highly variable, depending among other things on the duration of contact.

3. Heat transfer measurements can be interpreted as showing that the contact area is much smaller than the apparent area for some operating conditions.

It is hoped that redesign of some of the equipment and emphasis on different output data (electrical rather than thermal) will sharpen and extend these conclusions.

EQUIPMENT MODIFICATIONS

An overall view of the experimental apparatus is shown in Fig. 1. A graphite block is held against a 30 cm diameter steel wheel by a sample holder which is suitably instrumented to yield the forces on the graphite. The previous design of the sample holder (Fig. 2) was modified in two ways. The first change was required by the fact that the samples were much wider than the 3 mm wide rim of the moving wheel, so that contact between the two parts could occur on the sides of the wheel as well as on the edge as a groove was worn into the sample. This uncertainty in even the nominal contact area made conclusions from heat transfer and electrical measurements uncertain. Samples used in the current work were shaped such that contact could occur only on the edge of the disk (Fig. 3).

The second change in the sample holder related to the ability of the graphite piece to follow the motion of the disk edge. The out of roundness of the disk was small, not more than 0.1 mm, but at high rotation rates, this leads to large accelerations for a point on the edge. If the graphite piece is not in continuous contact with the edge, thermal and electrical measurements are difficult to interpret. The portion of the support structure holding the sample was, consequently, redesigned in order to significantly reduce the sprung mass, Fig. 4. The graphite block is mounted on a light arm which is constrained by a spring. The weight and spring are sized so that the natural frequencies associated with the support system is larger than the frequencies related to the rotating disk. The contact force can be changed either by changing springs, or by compression of a given spring. This design

modification restricts the operating mode to that in which the normal force is constant. The constant wear mode used in some of the earlier work requires locking the spring and a return to the more massive constraint.

The drive for the steel disk was changed from the $1\frac{1}{2}$ horsepower Graham drive to a 3 horsepower dc motor with an ignitron controlled variable armature current. This drive permits the speed to be varied over a wider range than previously attainable, and the speed can be maintained constant for long periods of time.

Another change in the experiment was in the method of evaluating the state of the contact region. Previously thermal measurements were used, but now an electrical evaluation was tried. The quantity examined was the steady and time dependent component of the contact resistance between the disk and the graphite block. To obtain this, a 0.1 ampere current was made to flow through the contact and the resulting voltage drop was monitored. This technique requires that an electrical connection be made to the moving disk by an electrical contact of better quality than that associated with the contact under study. To this end, brushes were made from copper wire to contact the wheel (Fig. 5). These could be made superior to the graphite contacts by virtue of their larger contact area, their use of thin metal fibers, and the possibility of locating them nearer the rotation axis where the contact speed was much smaller. Both a current brush and a voltage brush were used to make the voltage drop measurement easier to interpret. The circuit used is shown in Fig. 6.

EXPERIMENTS

The shaped carbon block was mounted on the holder so that the forces on the block could be measured with the strain gage balance, and the temperature could be determined by a thermocouple imbedded in the block. The electrical contact resistance was observed in an oscilloscope. The disk was operated with peripheral speeds in the range from zero to 70 M/sec.

A characteristic speed for thermoelastic phenomena can be defined as

$$V = \frac{\pi}{1.56} \frac{1-\nu}{1+\nu} \frac{k}{\alpha\mu G a}$$

where ν is Poisson's ratio, α is the coefficient of thermal expansion, G is the modulus of rigidity, μ is the friction coefficient, k is the thermal conductivity, and a is a length related to the size of the contact area. This speed gives the velocity where the frictional dissipation is sufficient to maintain the temperature of a thermally raised portion of the surface of radius a by thermoelastic effects for the case where there is no wear (5). The effect of wear on this speed is covered in the work of Dow and Burton (6). For the materials used here with small wear rate, and for a critical size equal to the width of the disk rim, the characteristic velocity is about 40 M/sec. The material properties of the graphite were not measured. Uncertainties in the various physical properties lead to large uncertainties in V. This velocity could be 50% larger or smaller than the calculated value, but the experiments covered this range.

RESULTS

Measurements of the friction force as a function of speed and

normal force are shown in Figures 7 and 8. The data show no consistent pattern over the speed and normal force range observed, no break or discontinuity appears as the speed is increased. Different pieces of graphite gave different results, and when a measurement was repeated for a single sample by varying the speed and then returning to the initial speed, the results did not repeat. Apparently something has to be controlled that is not now known in order to get consistent results. A study of this problem is now being pursued. The nominal value for the friction coefficient is consistent with the results obtained earlier.

The observation of the contact resistance is of some interest because it furnishes a setting for the other measurements. The observed voltage drop across the contact had the appearance of a white noise of considerable bandwidth. There was no indication that the contact was jumping, nor did the nature of the resistance fluctuation change with speed. The electrical measurements thus showed that the contact dynamics were under control and also corroborated the friction results in showing no significant qualitative change in the contact area over the range of variables used.

The temperature of the graphite increased with time of contact with the moving disk, but gradually approached an asymptote. The final temperature tended to increase as the speed increased, but even this showed some variation from sample to sample. A typical curve of final temperature as a function of sliding speed is shown in Fig. 9.

CONCLUSIONS

The high speed rubbing apparatus at Northwestern has been modified so that various types of data can be interpreted in an unambiguous manner. Electrical, thermal, and mechanical data are now obtainable.

Experimental data obtained for a steel-graphite contact with the modified apparatus did not give any evidence that thermoelastic effects were important in the range of variables investigated. Either the range investigated was not broad enough, or the effects are more subtle than expected. Large variability in the data obtained indicate that some important parameters are not yet understood or under control.

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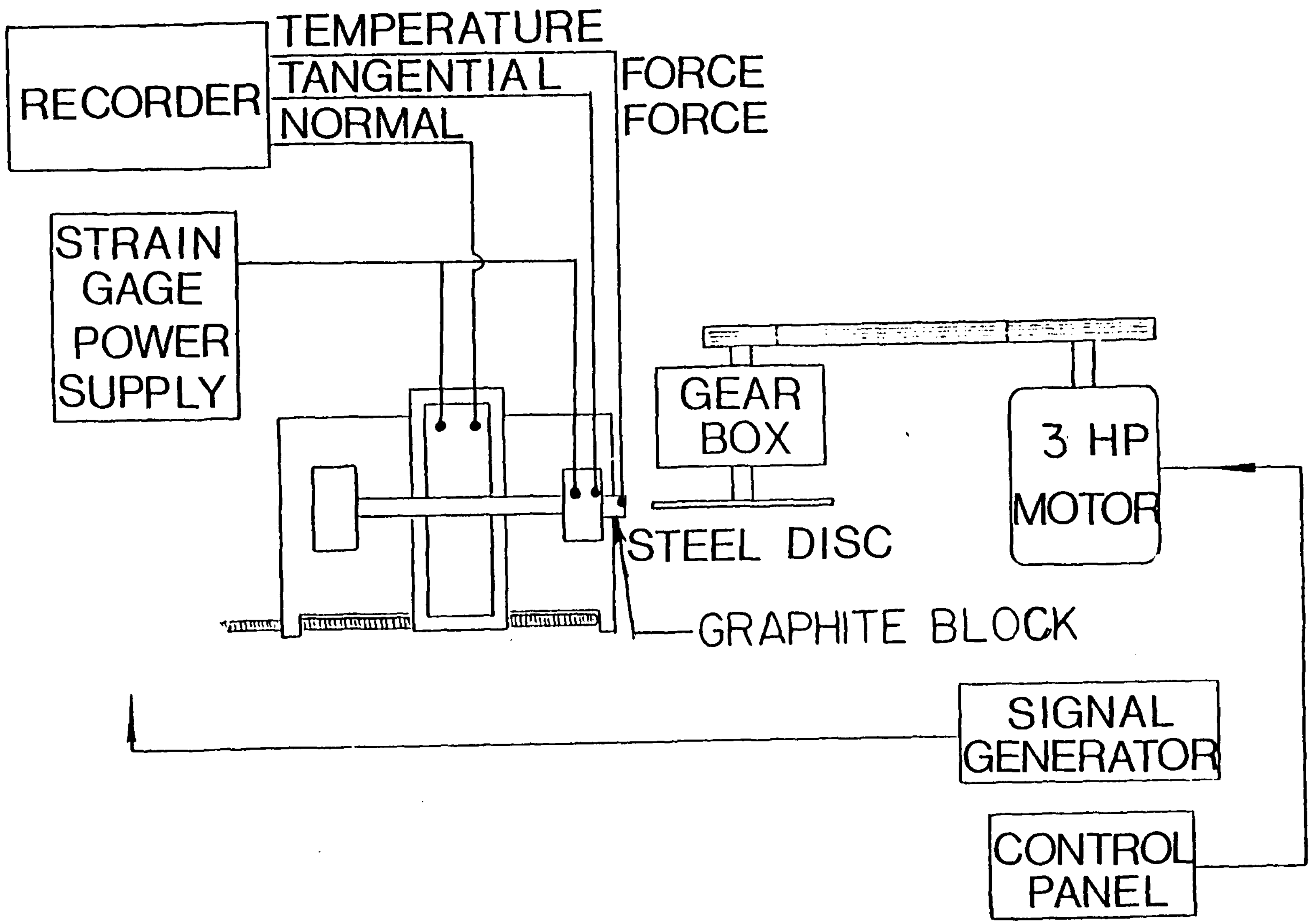

Figure 1. Schematic Diagram of Experimental Equipment

◇: STRAIN GAGE LOCATION

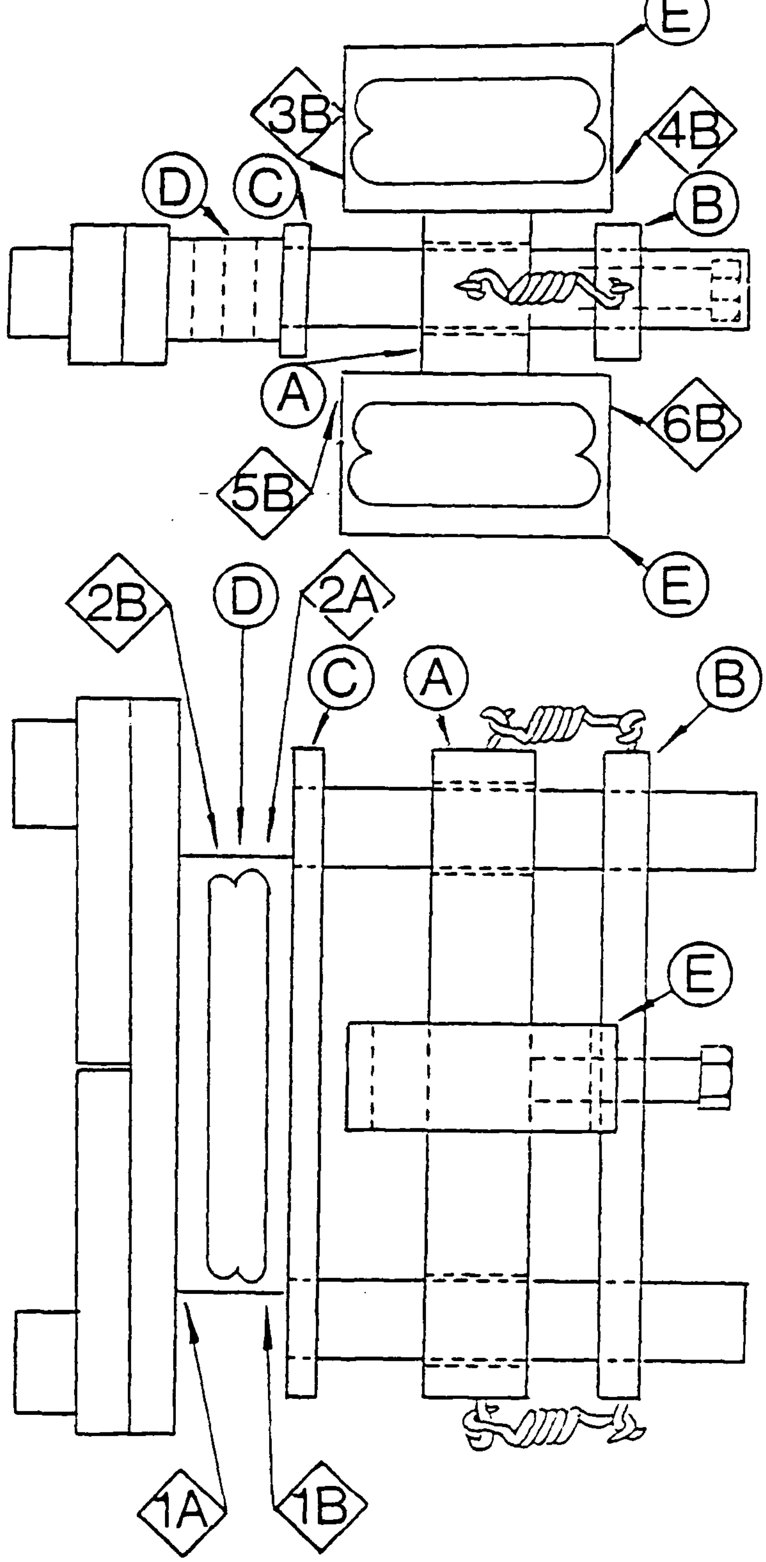

Figure 2. Specimen Holder Assembly

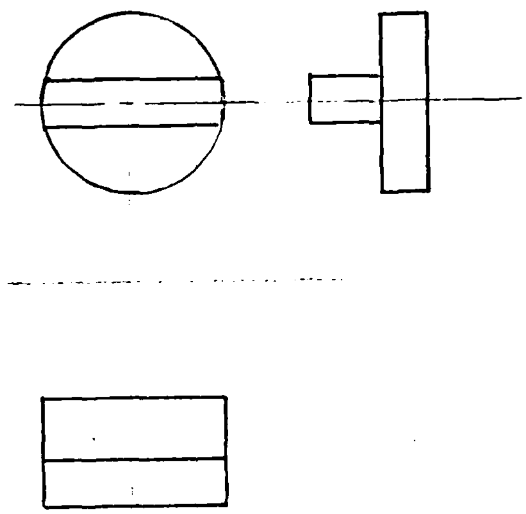

Fig. 3. New Graphite Block

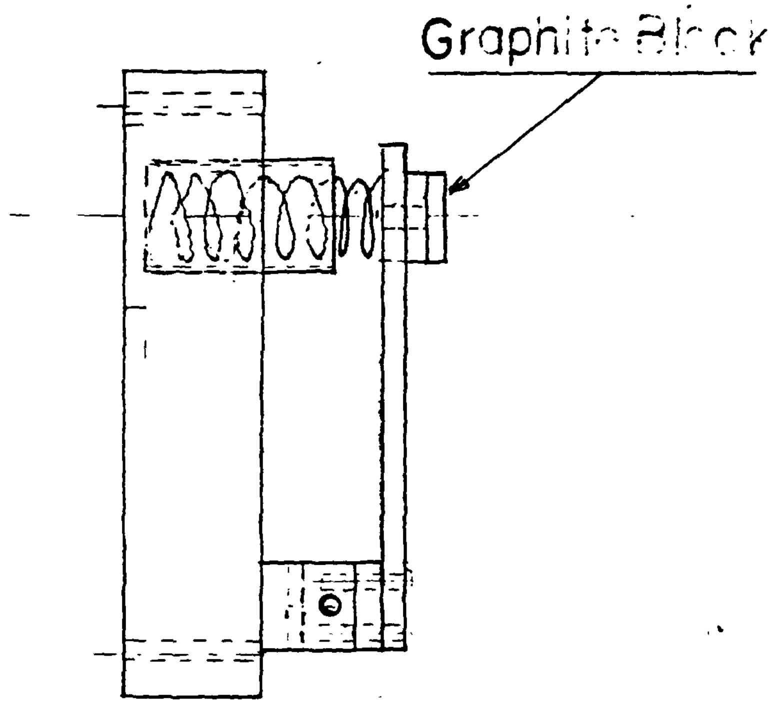

Figure 4. New Block Holder

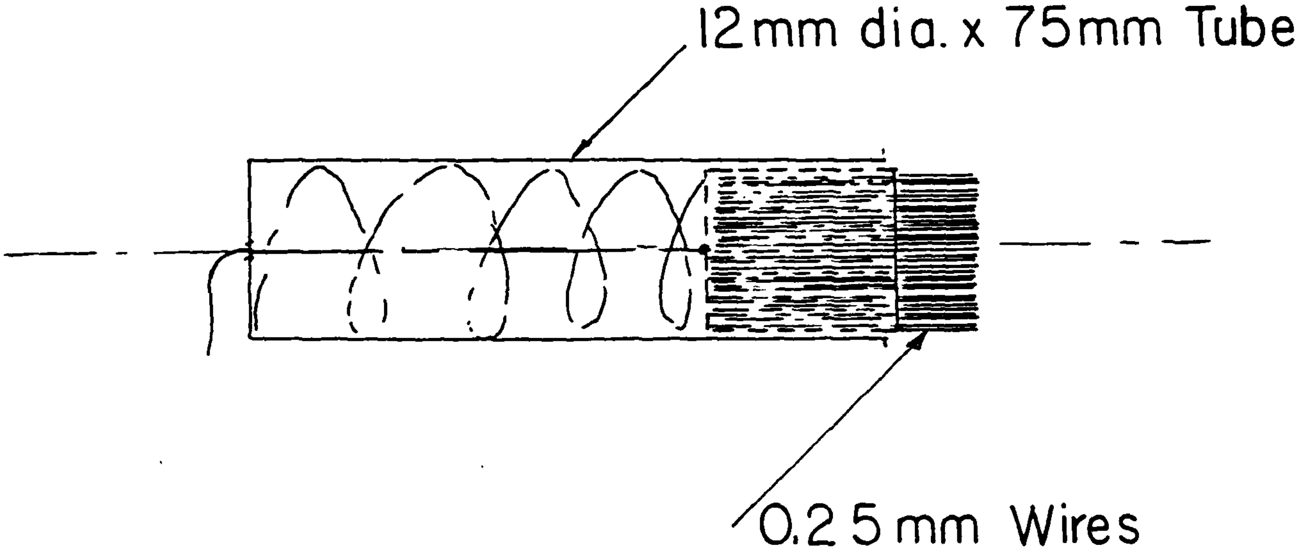

Fig. 5. The Wire Brush

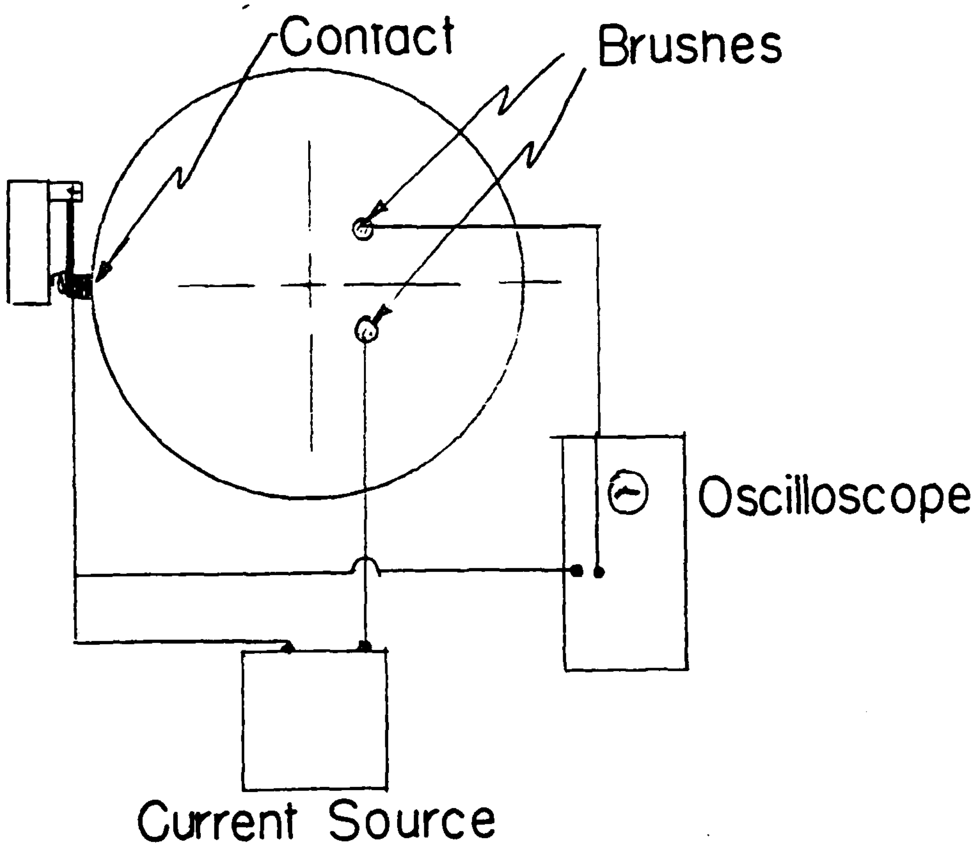

Fig. 6. Electrical Circuit to Obtain Contact Resistance

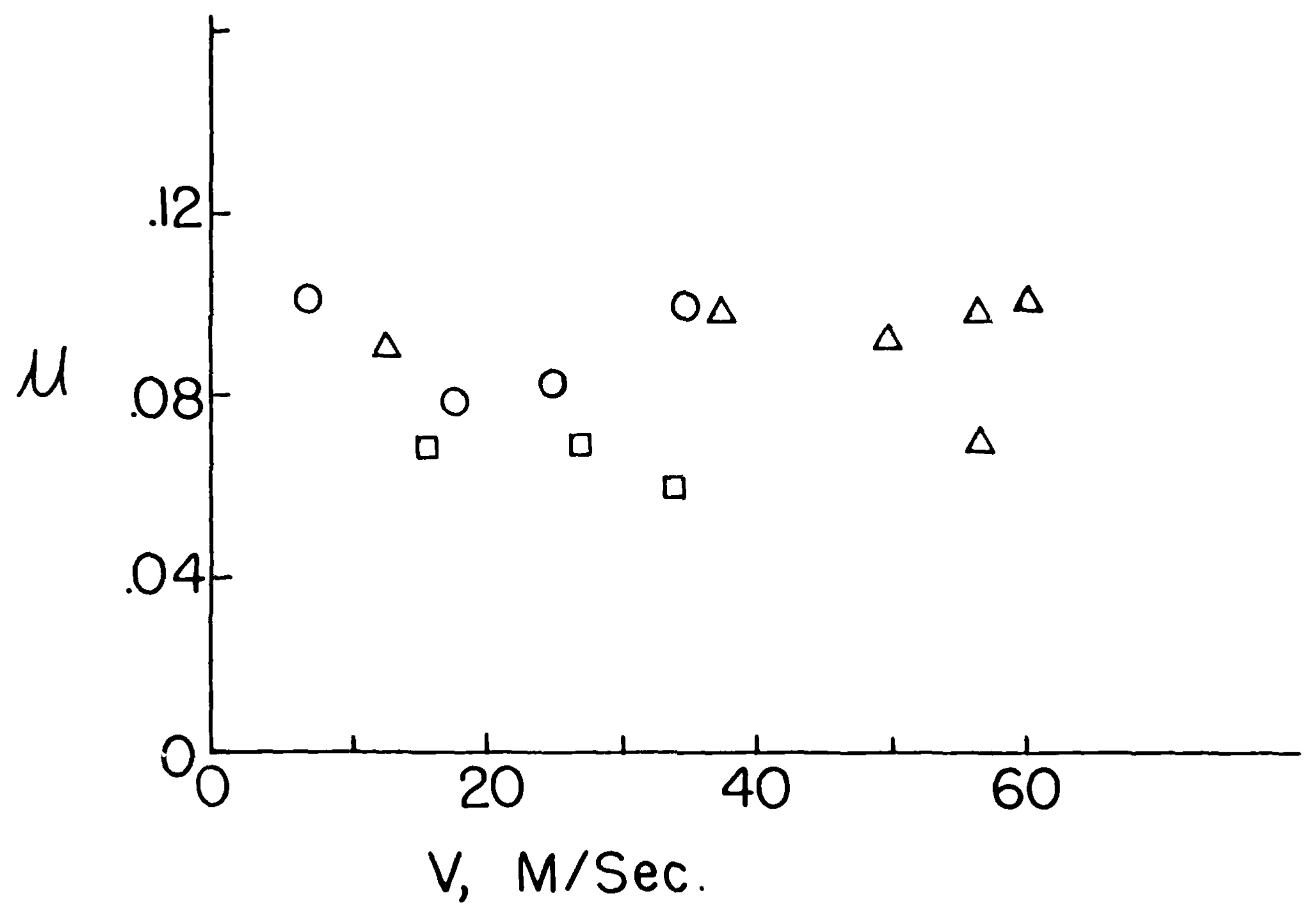

Fig. 7. The Friction Coefficient

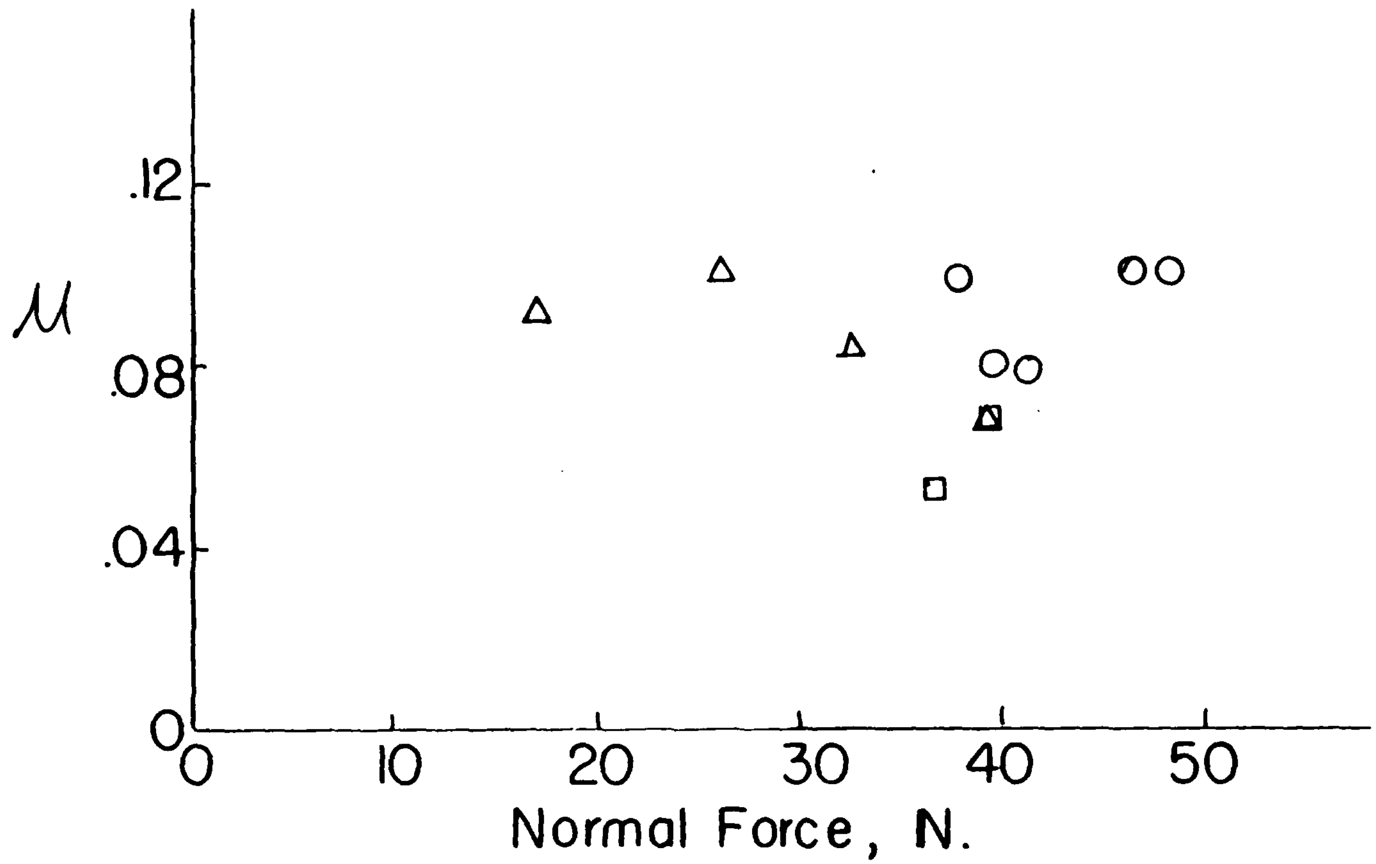

Fig. 8 The Friction Coefficient

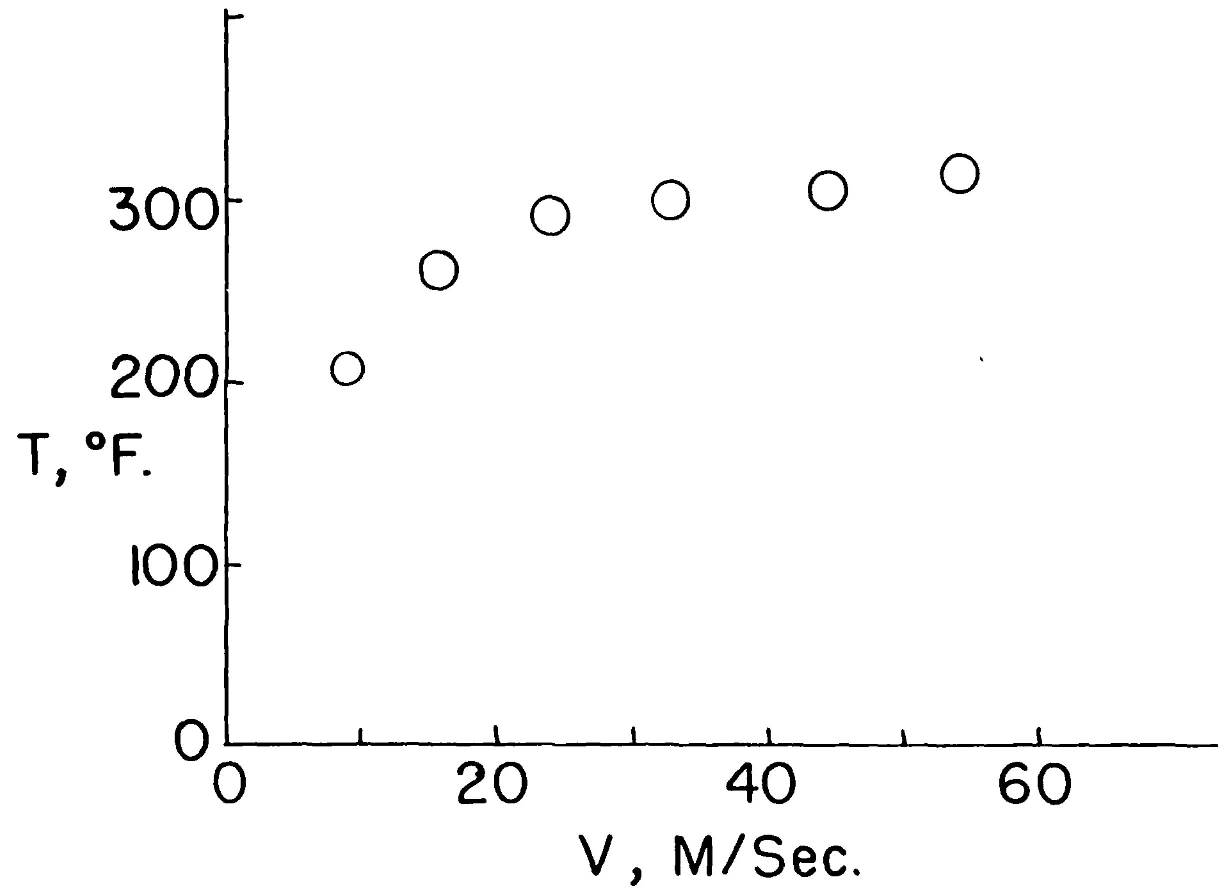

Fig. 9. Block Temperature vs. Rubbing Speed

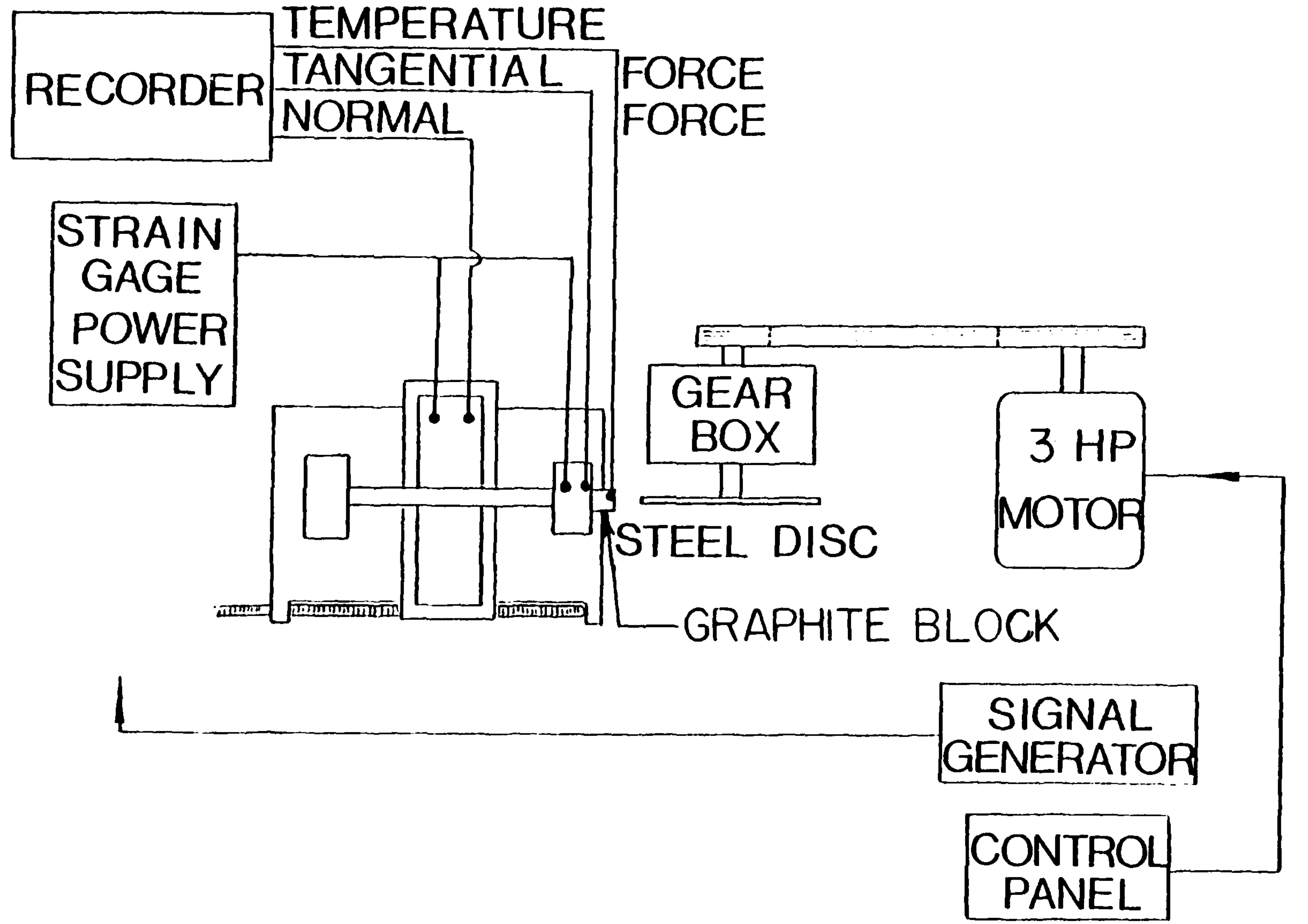

Figure 1. Schematic Diagram of Experimental Equipment

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